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BOUNDARY LAYER RELATIONSHIPS RESULTING FROM AN APPROXIMATION OF THE VISCOSITY OF EQUILIBRIUM DISSOCIATING AIR

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ABSTRACT

Discussion of the relationship between the viscosity laws of a perfect gas and equilibrium dissociating air. It is shown that if the enthalpies and velocities on the outer boundary of the boundary layer and the wall enthalpies for a perfect gas and for equilibrium dissociating air coincide, then the friction and heat-transfer characteristics coincide for both viscosity laws.

It was shown in (Ref. 1) that when an investigation is made of the gas boundary layer on a plate with a constant Prandtl number and the viscosity law /971*

$$\frac{\mu\rho}{\mu_\infty\rho_\infty} = \left(\frac{i}{i_\infty}\right)^{n-1} \tag{1}$$

the solutions obtained for the boundary layer of a perfect gas with the viscosity law

$$\frac{\mu}{\mu_\infty} = \left(\frac{T}{T_\infty}\right)^{n}. \tag{2}$$

* Note: Numbers in the margin indicate pagination in the original foreign text.

may be employed. Here ρ is the density; μ -- viscosity; T -- temperature; i -- gas enthalpy.

The figure shows the dependence of $\mu\rho/p$ (p -- pressure) on the enthalpy and pressure according to data given in (Ref. 2) (upper curves), and (Ref. 3) (lower curves). Although the data in these articles differ considerably (for large enthalpies the viscosity is 20% higher in Soviet data), they are closely approximated by the dependence

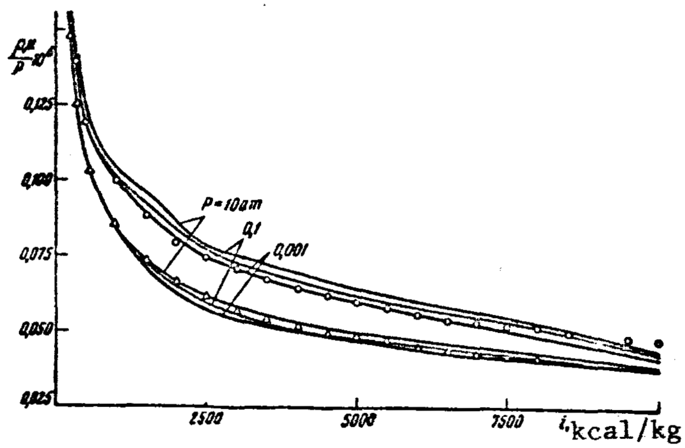
$$\rho\mu / p = C i^{(n-1)}, \tag{3}$$

from which (1) follows.

An approximation of (3) is also shown in the figure by the dots. If $[\rho] = \mathrm{kg\ sec^2/m^4}$, $[\mu] = \mathrm{kg\ sec/m^2}$, $[p] = \mathrm{kg/cm^2}$, $[i] = \mathrm{kcal/kg}$, we may find the following on the basis of the data given in (Ref. 2): $C = 0.88 \cdot 10^{-6}$, $n = 0.685$. We may find the following on the basis of data given in (Ref.3): $C = 1.04 \cdot 10^{-6}$, $n = 0.635$.

An approximation of (3) closely represents the law of the viscosity change in the 0.00. am $\lesssim p \lesssim$ 100 am and $i \lesssim$ 10,000 kcal/kg range. These enthalpies correspond to braking enthalpy during motion in the atmosphere at velocities of $V \lesssim$ 10 km/sec.

The boundary layer equations for equilibrium dissociating air coincide in form with similar equations for an ideal gas, when the temperatures are expressed by the enthalpy. In this case, if we can assume that the Prandtl number is constant for equilibrium dissociating air, /972 the results obtained in (Ref. 1) may be briefly formulated as follows. When there is agreement between the values of the enthalpy and velocity at the outer boundary layer edge and the enthalpy at the wall for an



ideal gas and equilibrium dissociating air, the characteristics of friction and heat exchange coincide for both viscosity laws. For example, for an ideal gas with the viscosity law (2), in the case of T_w = const and Pr = const, the friction coefficient can be quite accurately represented in the following form (Ref. 4)

$$C_f\sqrt{\mathrm{Re}_\infty} = 0{,}664\left[0{,}45 + 0{,}55\frac{T_w}{T_\infty} + 0{,}09\,(\gamma - 1)\,M_\infty^2\sqrt{\mathrm{Pr}}\right]^{-\frac{1-n}{2}}. \tag{4}$$

This formula assumes the following form for equilibrium dissociating air

$$C_f\sqrt{\mathrm{Re}_\infty} = 0{,}664\left[0{,}45 + 0{,}55\frac{i_w}{i_\infty} + 0{,}09\frac{u_\infty^2}{i_\infty}\sqrt{\mathrm{Pr}}\right]^{-\frac{1-n}{2}}.$$

The equations of state are different for an ideal gas and equilibrium dissociating air. However, if allowance is made for the fact that the influence of the pressure gradient is relatively small for a greatly cooled wall (Ref. 5) (and the equation of state is expressed in the boundary layer through this term), the conclusions presented above may be approximately extended to the boundary layer with pressure gradient.

Similar conclusions may be drawn regarding the boundary layer of equilibrium dissociating air.

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